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THIS ISSUE

Some Problems
Associated with
Compressor Lubrication

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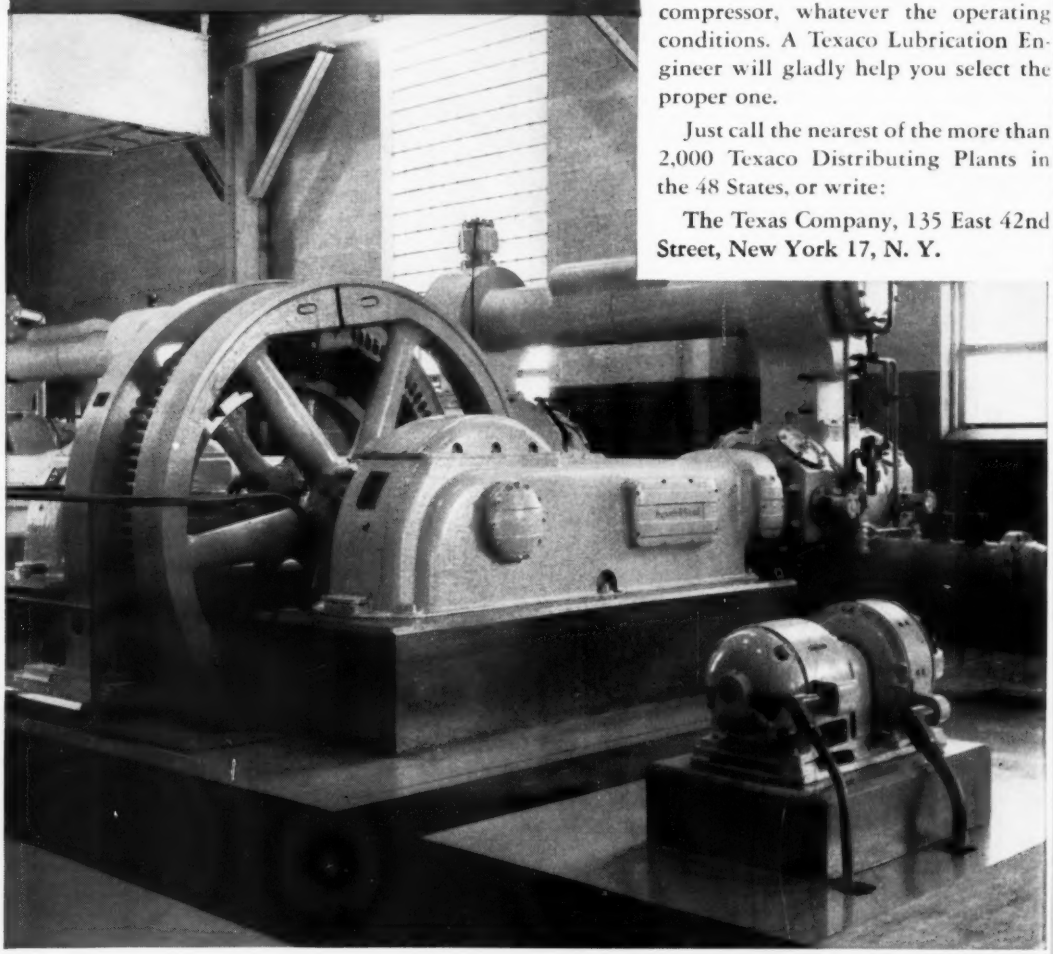

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FOR ALL OPERATING CONDITIONS

LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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Some Problems Associated with Compressor Lubrication

COMPRESSORS are used in so many different applications that they may well be judged as one of industry's most useful tools. The advancement of their use has been so closely allied with industrial progress that further expansion in compressor applications appears to be without limit. In order to keep pace with industrial development it has been necessary to increase the output of these machines by increasing their size and horsepower as well as the pressure and speed at which they operate. These improvements have not only been made for compressors handling air but for a wide variety of gases used in refrigeration, refinery operations, chemical processes, gas transmission and the rapidly expanding petrochemical industry. There is also a trend to incorporate automatic push button devices to improve control and reduce the attention required by an operator. These changes have placed increasing demands on the necessity of proper lubrication to insure satisfactory operation. This not only requires the careful selection of lubricants to meet the specific needs of the compressor and its allied equipment, but care must be exercised to assure that the lubricants reach the friction surfaces free of contaminants and in the proper amount.

Early compressors were lubricated by drip feed cups filled with animal oils such as sperm oil. These oils oxidize readily and decompose under high temperatures forming varnish-like or gummy deposits. High pressure compression with its attendant high temperatures was not commercially successful until after petroleum became readily available in 1862. The first petroleum oils were superior to fatty oils as lubricants but were paraffinics high in carbon residue and still left excessive carbonaceous deposits. It was not until 1900 that the low carbon residue Gulf Coast and California naphthene crudes became available. Because of the reputation and established characteristics of paraffin base oils which make them suitable for many applications, it was many years before the ability of the newer naphthene oils to keep air compressor valves much cleaner was fully appreciated.

One of the first differences noted between the fatty oils and the new petroleum lubricants was that while the animal and vegetable oils would emulsify or mix with water and lubricate under wet conditions, the mineral oils would not. It was soon found, however, that a few percent of fatty oil added to petroleum oils made them emulsifiable. Such oils, commonly referred to as compounded oils, may be used for cylinder lubrication when the air or gas contains a high percentage of moisture or condensable liquid.

In the late 1930's it was discovered that the addition of certain oil soluble soaps to straight

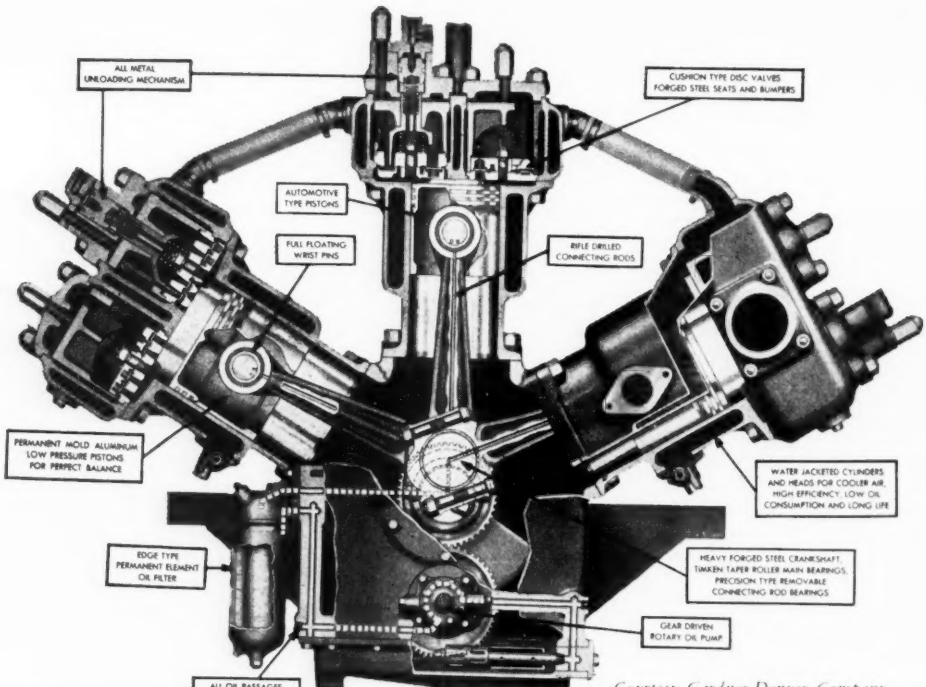

ALL METAL UNLOADING MECHANISM
CUSHION TYPE DISC VALVES FORGED STEEL SEATS AND BUMPERS
AUTOMOTIVE TYPE PISTONS
FULL FLOATING WRIST PINS
RIFLE DRILLED CONNECTING RODS
PERMANENT MOLD ALUMINUM LOW PRESSURE PISTONS FOR PERFECT BALANCE
WATER JACKETED CYLINDERS AND HEADS FOR COOLER AIR, HIGH EFFICIENCY, LOW OIL CONSUMPTION AND LONG LIFE
EDGE TYPE PERMANENT ELEMENT OIL FILTER
HEAVY FORGED STEEL CRANKSHAFT, TIMKEN TAPER ROLLER MAIN BEARINGS, PRECISION TYPE REMOVABLE CONNECTING ROD BEARINGS
GEAR DRIVEN ROTARY OIL PUMP
ALL OIL PASSAGES DRILLED IN CRANK CASE
Courtesy Gardner-Denver Company

Figure 1 — Sectional view of a two-stage compressor unit. Note features of the pressure lubricating system.

mineral oils improved their detergent or cleansing properties. This development was accompanied by the incorporation of many different types of additive agents in lubricating oils, such as oxidation and rust inhibitors, pour point depressants, viscosity index improvers, and antifoam agents to improve their performance in certain machines, including compressors in their varied applications. Synthetic oils are being used in recent specialized applications where certain performance characteristics can not be attained by the use of naturally occurring petroleum material. Although their use has been relatively limited, synthetic lubricants will possibly enter the lubrication picture as further improvements are made and more knowledge is gained as to their performance characteristics.

COMPRESSOR TYPES

Compressors are generally classified into three principal types: (1) reciprocating piston compressors, comprising the conventional piston and cylinder, a crank mechanism to impart reciprocating motion to the piston, and valves to control admission and discharge of air; (2) rotary compressors in which compression is effected by the positive displacement of rotating elements; and (3) centrifugal or turbo compressors in which the air or gas is compressed by the dynamic action of rotating vanes or impellers.

FUNCTION OF A COMPRESSOR LUBRICANT

Proper lubrication is essential to the satisfactory functioning of the various sliding and rotating parts of these machines. The most important function of a lubricant is to reduce friction and minimize wear of the working parts. The lubricant must also provide an adequate piston ring and packing seal to prevent the escape of gas and to serve as a heat transfer medium. Valves must be lubricated without impairing their action by the formation of carbon. Bearings must be lubricated and protected against corrosion with minimum friction. In some applications the lubricant must also provide protection against rusting. Before discussing the selection of lubricants to perform these important functions it would be well to present some of the factors which must be considered in the problems associated with compressor lubrication.

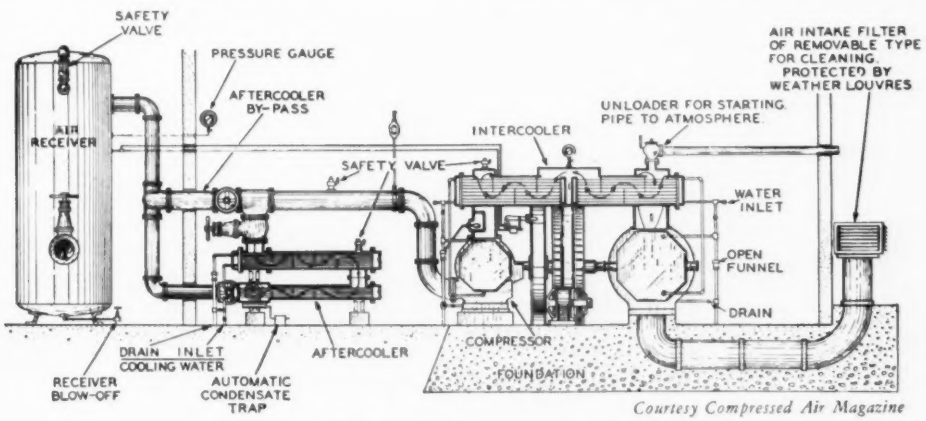
ADEQUATE INSTALLATION

Many problems which might be encountered in the operation and lubrication of compressors may be solved before they occur by giving careful attention to the proper installation of the compressor and providing for the necessary auxiliary equipment. This is not so much a factor with portable self contained units as for stationary installa-

tions. The compressor manufacturer usually provides this type of equipment; however, the customer must furnish complete information on the compressor requirements for the manufacturer to make adequate recommendations. The compressor should be located in a clean, well lighted area of sufficient size to permit cleaning, inspection and any dismantling which may be required. The foundation should be well designed to avoid transmission of vibration and alignment difficulties. If the unit is an air compressor, the air intake should be carefully located and equipped with an efficient filter of adequate size to prevent contamination by moisture, dust, smoke and fumes, paint, or other air borne materials which will accelerate deposit formation and wear of parts regardless of the type of lubricant used. The air intake should be of adequate size and as short and direct as possible, and the filter should be located to permit ease of cleaning. In some installations it is desirable to install a simple manometer gage on the intake pipe to determine when the filter requires attention. Where necessary, provisions should be made for surge chambers, knock out drums, intercoolers, aftercoolers, scrubbers, moisture and oil traps and related equipment to assure that the gas entering or leaving the compressor is properly cooled and as clean and dry as possible. All piping should be carefully arranged to avoid unnecessary pockets for oil and moisture to accumulate and suitable traps or drain valves installed. The piping to the compressor should be well supported to relieve the compressor of incidental stress and to avoid possible misalignment of cylinders. The discharge pipe and receiver or surge chamber should be of sufficient size to minimize vibration and should be equipped with traps or drains. Safety valves should be located in accordance with good engineering practice and provision should be made for the installation of necessary temperature and pressure indicating and regulating devices. An adequate supply of cooling water for cylinder jackets, cylinder heads, intercoolers and aftercoolers must be provided and temperatures regulated in accordance with manufacturer's instructions. The coldest water should normally be passed through the intercooler first and then to the cylinders to avoid condensation on the cylinder walls. The compressor and related driving equipment must be carefully aligned to avoid uneven wear and possible malfunction. All piping, valves, and accessory equipment must be thoroughly cleaned before installation. Pipe which has been welded or threaded always has some metal chips or welding slugs inside. If metal pieces, pipe scale, dirt and all foreign material are not carefully removed, they will be loosened by the flow of air or gas or liquid and will cause serious damage. It is necessary that a thorough study be carried out to insure adequate installation in order to avoid operation and lubrication problems.

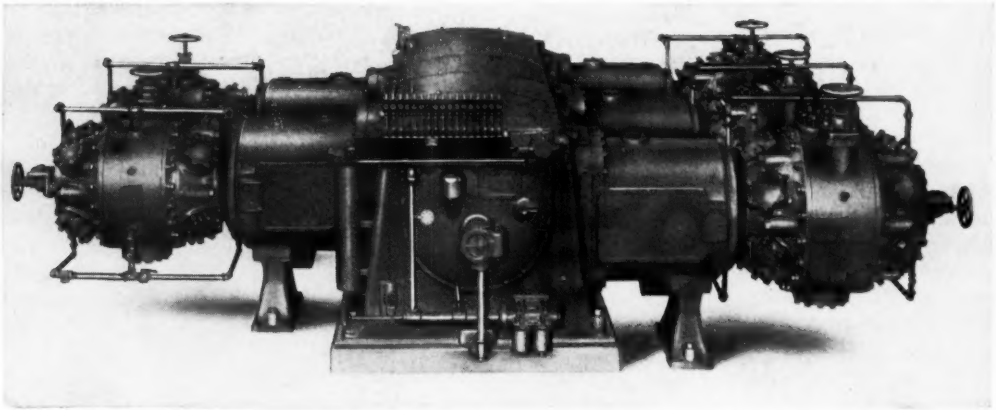
Break-In

The starting up and break-in of a compressor is a very critical period and if it is not carried out properly serious damage may be encountered. Manufacturer's instructions should be carefully followed and the unit should be thoroughly cleaned and inspected. Pistons, rings, cylinders, rod packing, bearings and piston rod should be well covered with oil during assembly and the crankcase and cylinder lubricators should be filled with the proper oil. The lubricator lines should be primed with oil and then disconnected at the point of application to insure an adequate supply of oil is available. During the initial run-in period the unit should be watched very closely to determine if any sign of overheating or other distress appears. All moving parts should be checked to see that they are properly lubricated and any excessive heating should be investigated. The break-in period usually involves relatively short runs at gradually



Courtesy Compressed Air Magazine

Figure 2 — Reciprocating compressor installation.



Courtesy Cooper-Bessemer Corporation

Figure 3 — Mechanical lubricator installation on horizontally opposed compressor unit.

increasing speeds and loads with frequent inspections to assure that dirt, metal chips, foreign particles, and water leaks are not being encountered. The oil around the packing glands, piston rods and valve chamber pockets should be inspected for any signs of finely divided metallic particles. The time when the oil has become absolutely clean and free of particles may serve as a guide that the packing is ready to seal against full pressure and the rings are seated in the cylinders. The compressor should not be considered fully broken-in until it can pull full load and pressure.

Wear and Over-Lubrication

One of the biggest problems encountered in compressor lubrication is that the operator, on observing wear, increases the amount of oil fed to the compressor cylinders. This problem is particularly applicable to air compressors where over-lubrication may result in excessive carbonization of the discharge valves and increased discharge temperatures. Wear is not ordinarily a problem in compressor lubrication provided the oil and air are kept clean. Extensive investigations have indicated excessive wear is generally associated with contamination of the intake air in the form of dirt, pipe scale, welding beads, rust particles, entrained moisture, and condensation, and is seldom due to insufficient lubrication. Misalignment, improper piston and ring clearances, and inadequate cooling will also cause increased wear.

During the break-in process it is desirable to use a liberal quantity of oil until the rings are well seated and the cylinders are glazed. However, when the unit is ready to pull full load the amount of oil should be reduced to the minimum required for satisfactory lubrication. Because of the many variables involving the size and speed of the compressor, the condition of the pistons, rings and cylinder walls, the viscosity of the oil, and whether it is fed by splash from the crankcase, injected into the intake air or by a separate force feed lubricator, it is inadvisable to establish any hard and fast rule as to the theoretically proper amount of oil that should be supplied to a cylinder. As a starting point to determine the proper feed rate, the lubricator should be set to deliver one drop of oil per cylinder per minute for every 1,000 square feet of cylinder surface swept per minute. The amount of oil used should approximate 1/10 pint per 10 hours per 1,000 square feet of cylinder surface swept per minute. After running a few hours pull one of the discharge valves and observe the interior surface of the cylinder. It should feel oily at the top but there should be no evidence of excess oil on the piston or in the discharge passages. Reset the lubricator until examination of the cylinder reveals a satisfactory condition. Once this is determined, measure the actual amount of oil consumed and use this as a basis for keeping the oil feed rate in line, supplementing by occasional inspections of the cylinders. The amount of oil fed to the piston rod packing should be similarly reduced until the rod shows a thin continuous film and no excess oil coming from the packing vent or accumulating in the cylinder yokes.

Force feed lubricators and lines should be cleaned and inspected at periodic intervals to insure the correct amount of clean oil reaches the lubrication points. Where liquid type sight feed lubricators are used, the drops of oil will carry over a trace of the sight glass fluid into the cylinders so that it is necessary to replenish the liquid every few months. The rate of carryover is relatively low for straight mineral oils where water or mixtures of water and glycerine are used; however, some additive type oils containing detergent or dispersant components may carry over all the sight glass liquid in a matter of days. The displacement of the sight feed liquid by the oil does not affect

the oil feed rate but does finally make it impossible to observe the number of drops being fed. Such a problem is not difficult to solve, however, as lubricator solutions have been found which will provide the desired performance for particular additive oils. Unfortunately, no one lubricator solution has yet been found that will be satisfactory for all types of additive oils.

In the splash system the oil in the crankcase is splashed by a scoop on the ends of the connecting rods onto the bearings and cylinders. The amount of splash can be regulated by varying the length of the scoop or the oil level. The oil level should be checked daily and oil added or drained off as necessary. Too low an oil level may cause lubrication failure. Too high an oil level may cause foaming and high oil consumption. Oil control rings in single acting splash lubricated compressors should be maintained in satisfactory condition to prevent excessive oil consumption.

Deposits

Another important problem that may be encountered in compressor lubrication is the formation of deposits. Perhaps the most objectionable place for deposits to form is on the discharge valves where they can impair the action and result in excessive discharge temperatures. Deposits in intercoolers, aftercoolers, pistons and crankcase may also reduce the efficiency of the unit. The formation of these deposits may be caused by several of the following factors.

1. Excessive discharge temperatures
2. Excessive oil consumption
3. Dirt, rust, pipe scale, etc.
4. Gas contamination
5. Unstable gases
6. Reaction between gas and lubricating oil
7. Water contamination
8. Wrong kind of oil.

As there are an infinite number of conditions where deposits may be formed in gas compressors the following discussion will be limited to air compressor valve deposits:

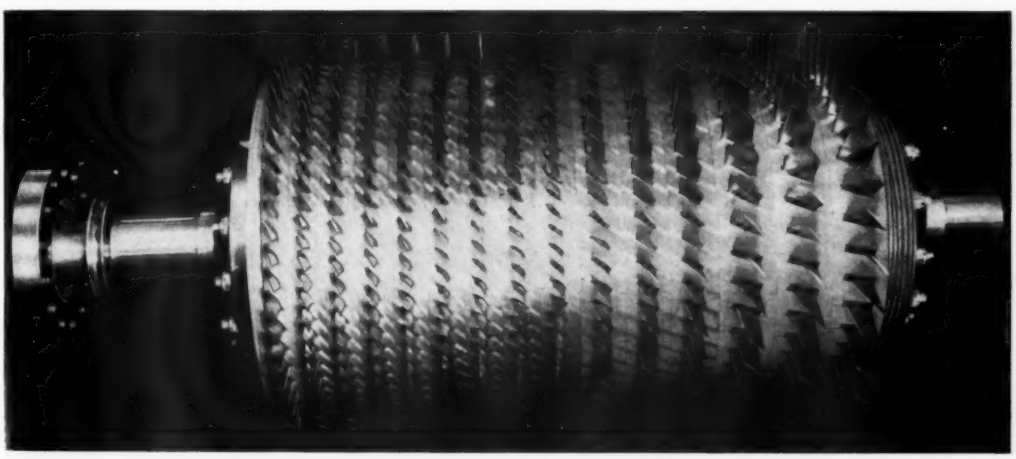
The intake valve of an air compressor normally does not present a lubrication problem since it is kept cool by the incoming air; however, even in the best regulated compressors, carbon may deposit on the discharge valve. Since it is located in the discharge air stream, the discharge valve will be at the temperature of the compressed air. Disregarding the cooling effect of the jacket water and the heating effect of friction and wire drawing, the discharge air temperature will theoretically reach the temperatures shown in Table I.

TABLE I

Air Compressor Discharge Temperature

Compression Gage Pressure, p.s.i.	*Approximate Compression Temperature °F.*	
	Single Stage	*Double Stage*
50	350	210
100	500	250
200	—	310
300	—	350

In a well cooled compressor the discharge temperatures will be under these values; however, discharge valve leaks or higher than normal intake temperatures will result in values above the theoretical. One of the easiest ways to form a carbonaceous deposit is to spread a thin film of oil on a hot surface in the presence of air which is exactly



Courtesy General Electric Company

Figure 4 — Axial-flow compressor rotor for gas turbine locomotive power plant. Bearings lubricated from pressure system.

the condition existing at the discharge valve of an air compressor. Excessive quantities of lubricating oil and contaminating materials in the intake air stream will greatly accelerate the formation of these deposits. The amount and nature of the deposit will also depend on the type of oil, the compression temperature, and the design of the valve.

In order to determine the effect that various type oils may have on carbon formation, five different type commercial oils were evaluated in a series of laboratory tests[1]. Each of the oils selected had a viscosity of approximately 300 Saybolt Seconds at 100°F. Their composition and physical tests are shown in Table II.

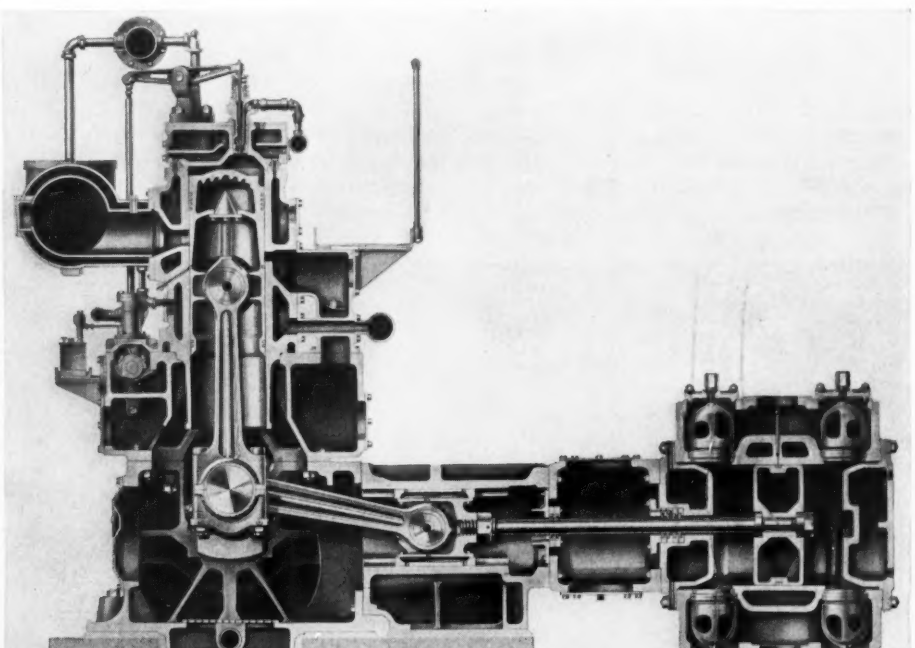
The results of these laboratory tests are shown in Table III and the oils are listed on the basis of their service performance.

It will be noted that neither the oxidation resistance nor the carbon residue tests evaluated the oils in the order of their service ratings. Therefore a special test was set up in which the oil was exposed in a thin film on an iron plate for 24 hours at various temperatures and the percent residue determined. This thin film residue test checked very well with service experience. A similar correlation may be drawn between the thin film residue test and the evaporation rate as it will be seen that the oils having the greatest evaporation rate exhibit the lowest deposit forming tendencies. The flash point test also compares with evaporation rate and carbon formation. On the basis of these data and extensive service experience, it has been found that the most volatile oils form the least amount of carbon. From a valve operating standpoint, as light and as volatile an oil as possible should be used for air compressor lubrication. The cylinder and bearing lubrication requirements, however,

TABLE II
Composition and Identification Tests

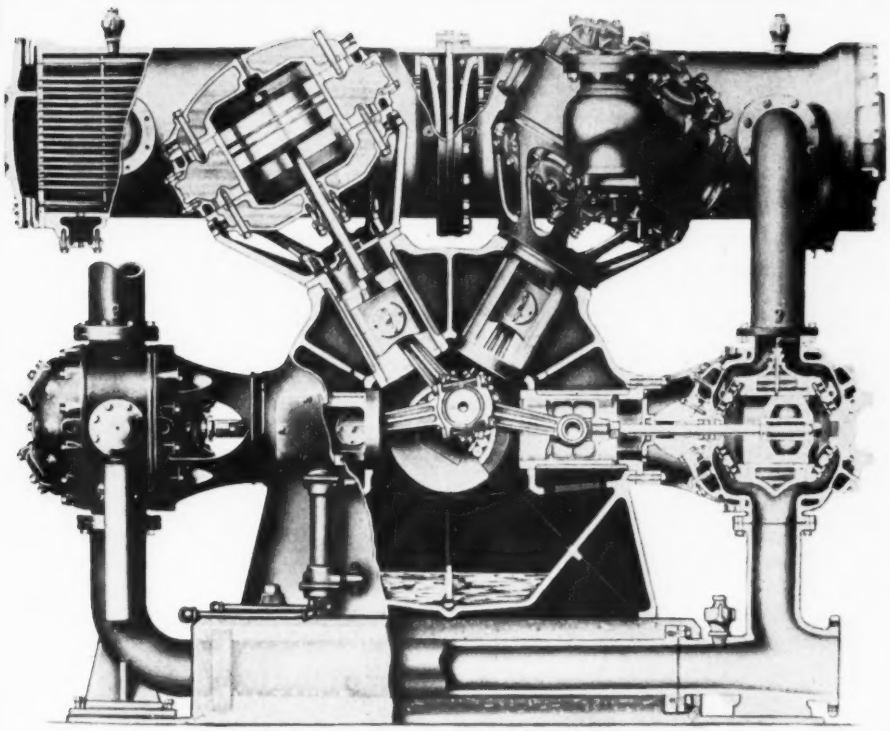
Oils	Viscosity, SSU at 100° F. ASTM D-88	Gravity, °API ASTM D-287	Saponification Number ASTM D-94	Ash, % ASTM D-482
Inhibited Naphthene	306	23.1	0.03	0.00
Straight Naphthene	306	23.1	0.03	0.00
Compounded Napthene (3%)	293	23.1	6.50	0.01
Detergent Paraffin	345	27.5	1.60	0.24
Straight Paraffin	323	29.3	0.03	0.00

[1]Compressor Lubrication, by K. L. Hollister, Lubrication Engineering, Aug. 1950, 158-60.



Courtesy Worthington Corporation

Figure 5 — Sectional view of gas engine driven compressor unit.



Courtesy Joy Manufacturing Company

Figure 6 — Semi-radial reciprocating two-stage compressor. Cylinders are lubricated by mechanical lubricator and all bearings are under oil pressure from gear type pump located in crankcase.

may call for a heavier oil which results in a compromise between viscosity and volatility.

AIR COMPRESSOR EXPLOSIONS AND RECEIVER FIRES

In the previous discussion it was pointed out that excessive lubrication, particularly with unsuitable oils combined with contaminated air and excessive discharge temperatures, could result in the formation of carbonaceous deposits on the discharge valves. These deposits not only impair the action of the valves but if they begin to hold the valve open, the discharge temperature will increase progressively with each stroke of the compressor. If the compressor is not shut down relatively soon after this develops, the discharge air may become hot enough to cause spontaneous ignition of the deposit. With further development of heat the deposit can become incandescent and under certain conditions may weaken an area in the high pressure section to cause a rupture or ignite an accumulation of oil mist and vapor in the discharge area.

The occurrence of such accidents is extremely rare, however, the unsound practice of demanding

TABLE III
Carbon Formation Indicators

Oils	Service Performance Rating	Oxidation Resistance Rating	Carbon Residue, % ASTM D-189	Flash Point COC, °F. ASTM D-92	Evaporation Rate Oz/sq. ft/hr. at °F. 250	350	450	Thin Film Residue, % at °F. 250	350	450
Inhibited Naphthene	1	1	0.02	385	.020	.026	.096	19	5	4
Straight Naphthene	2	4	0.01	380	.016	.031	.076	14	9	6
Compounded Naphthene	3	5	0.03	395	.020	.031	.076	16	10	10
Detergent Paraffin	4	2	0.37	435	.006	.010	.043	37	16	10
Straight Paraffin	5	3	0.01	440	.003	.006	.036	37	22	13

Factors Which Control Dependable Compressor Operation

1. **Adequate installation** – Manufacturers' instruction books provide an excellent guide for the proper installation of the compressor and its auxiliary equipment, in addition to recommended operation, lubrication and maintenance practices which should be carefully followed.

2. **Controlled lubrication** – Supply the proper amount of clean oil to lubricate the cylinders, valves, rods and bearings. Drain and clean the crankcase and lubricators at necessary intervals consistent with operating conditions. Effective lubrication can best be judged by periodically observing the condition of the lubricated surfaces.

3. **Clean Intake Air or Gas** – Filters, scrubbers, knockout drums, separators and related equipment should be cleaned and adjusted at frequent intervals to insure that the gas or air entering the compressor is properly cooled and as clean and dry as possible.

4. **Adequate circulation of cooling water or air** – Insures satisfactory cylinder operating temperatures and efficient performance of intercoolers and aftercoolers. Cylinder temperatures should be sufficiently high to avoid "sweating" or condensation of gases compressed, or from moisture in the intake air.

5. **Efficient intercoolers and aftercoolers** – Maintain in a clean condition to insure effective cooling of the compressed gas and separation of condensed liquid. Drain receivers, intercoolers and traps daily – removal of water and condensed liquid prevents liquid carryover, rusting and excessive accumulation of oil.

6. **Satisfactory valve operation** – Inspect valves and discharge passages at frequent intervals and clean when necessary.

7. **Periodic inspections of** – Cylinders, piston assemblies, packing, running gear and regulating devices will aid in maintaining the compressor in top operating condition.

8. **Properly selected lubricating oil** – Provides effective lubrication of friction surfaces and minimizes the formation of objectionable deposits. Storage and dispensing equipment should be kept in a clean condition and free of moisture, dirt or other contaminating materials.

Factors Which May React Against Efficient Compressor Operation

1. **Excessive vibration and poor alignment** – Can result in accelerated wear if compressor is not installed properly.

2. **Excessive oil feed** – Will lead to formation of objectionable deposits on valves, cooling surfaces, and oil lines. Maintain proper oil level in reservoir and correct oil pressure to bearings.

3. **Compression of dirty air or gas** – Will cause scoring or abrasion of cylinder walls, piston rings and valves and will hasten the formation of deposits.

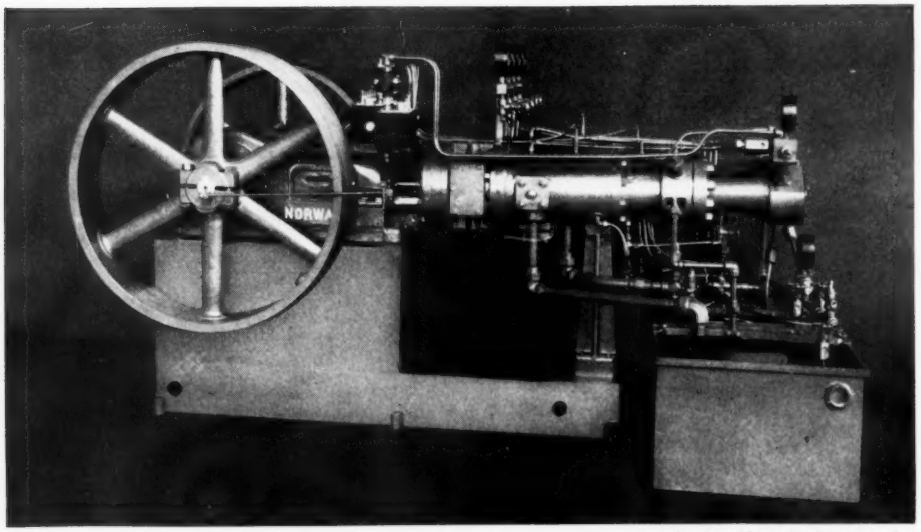
4. **Dirty or inefficient intercoolers and aftercoolers** – Will result in excessive discharge gas temperatures and accelerate wear and deposit formation.

5. **Entrained moisture or liquid "slugs"** – Will seriously affect cylinder lubrication and should be avoided by adequate cooling and maintenance of separators, knockout drums, intercoolers, etc.

6. **Air leaks or blowby** – Due to leaky valves or stuck piston rings will lower compressor output and materially increase discharge temperatures. Frequent observation of compressor pressures and temperatures are desirable to check for signs of possible malfunctioning.

7. **Knocking or excessive noise** – May be due to worn or improperly fitted bearings, loose flywheel, worn crossheads, loose piston, insufficient head clearance, deposits in clearance space or liquid in cylinders. Become accustomed to the sound of the compressor when operating normally as any unusual sounds will often warn the operator of possible trouble.

8. **Careless selection of lubricating oil** – Suitable precautions should be taken to assure that the right oil is used in the right location.



Courtesy Norwalk Company, Inc.

Figure 7 — Multi-stage compressor for pressures up to 25,000 pounds. Mechanical lubricator used for cylinders.

a high flash point oil to prevent them is not so rare. Extensive investigations[2,3] have been conducted and there has been a general agreement that an oil having the least tendency to form carbon should be used. These investigations have also established the fact that the flash point in the lubricating oil range has no relationship to the occurrence of such accidents.

The flash point of a lubricating oil is merely an indication of the temperature required to vaporize a sufficient amount of oil to form an inflammable mixture with air at atmospheric pressure when exposed to an open flame. Based on vapor pressure determinations made by observing the initial boiling points of oils under reduced pressure, approximately one percent oil vapor is required. Under higher pressures such as exist in an air compressor, considerably higher temperatures would be required to vaporize a sufficient amount of oil to form an inflammable mixture. Therefore, the formation of an inflammable mixture in the discharge side of the compressor is not so much a function of the flash point temperature as the concentration of oil mist from the oil which is continually being scraped off the cylinder walls by the piston rings and discharged through the valves. This is further reason to reduce oil consumption to the minimum required for satisfactory lubrication.

Experimental work[4] has shown that the lower limit of inflammability of an oil mist and air is essentially the same on a weight basis as for the oil in the form of a vapor. For ignition to occur in either the mist or the vapor state, its temperature must be raised well above the spontaneous ignition temperature which for lubricating oils may be from two to three times higher than its flash point.

Further work[5] has shown that there is little or no relationship between flash point temperature and spontaneous ignition temperature, and under less ideal conditions for ignition (i.e., when the rate of heat transfer from the point of ignition to the surrounding atmosphere is relatively high) considerably higher temperatures will be required to ignite the same material. This may be illustrated by Table IV which shows the variations between flash point, spontaneous ignition and minimum ignition temperatures for a wide range of lubricating oils. Considering the many thousands of compressors in daily operation and the relatively low number of air compressor explosions and receiver fires, these ideal conditions are rarely encountered and then only under very adverse circumstances.

As a matter of interest the above-mentioned investigations have shown that actual discharge valve deposits removed from malfunctioning air compressors may become exothermic at temperatures as low as 309°F.[3]. Work carried out by the Bureau of Mines[2] indicated the deposits may become exothermic at 482°F. This exothermic reaction temperature may be described as the tem

2U. S. Bureau of Mines Report of Investigations 4465, June 1949 by H. W. Busch, L. B. Berger and H. H. Schrenk.

3Mechanism of Explosions in Compressed Air Pipe Ranges, by R. Loison. Published by The Safety for Mines Research Establishment Ministry of Fuel and Power, Buxton, England.

4"Über Nebelexplosionen" ("Fog Explosions") by F. Huber and H. Wolff, Zeitschrift für angewandte Chemie, Vol. 36, 1923, pp. 373-377.

5"Diesel Engine Crankcase Explosion Investigation," by G. W Ferguson, Transactions of the American Society of Mechan Engineers, Vol. 74, 1952, pp. 7-21.

TABLE IV
Ignition Characteristics of Various Oils

Oils	Flash Point, COC, °F. ASTM D-92	Spontaneous Ignition Temperature, °F., ASTM	Minimum* Ignition Temperature, °F.
Naphthene Base Oils			
SAE-10	385	755	1500
SAE-30	395	775	1500
SAE-50	425	810	1500
Paraffin Base Oils			
SAE-10	410	730	1500
SAE-30	490	790	1500
SAE-50	500	795	1500
Heavy Duty Oils			
SAE-10	430	710	1500
SAE-30	440	780	1500
SAE-50	465	815	1500
Heavy Duty Oil Plus			
5% Diesel Fuel	400	780	1500
10% Diesel Fuel	300	730	1500
20% Diesel Fuel	260	735	1500

*Minimum ignition temperatures obtained in explosion tube apparatus using 2-in. x 1-in. x 0.02-in. electrically heated michrome igniter, 250°F. mixture temperature, air flow 1.45 lb. per min.

perature at which the deposit develops more heat than it can dissipate. When this temperature is reached the deposit becomes progressively hotter reaching an incandescent stage. The latter value (482°F) has been correlated with temperatures developed in similar compressor units in which explosions occurred. As shown in the wide variations in experimental results (from 309°F to 482°F) the exothermic reaction temperature will depend on the type of deposit formed and the heat transfer condition existing in the vicinity of the deposit.

Figure 8 illustrates the practical relationship of the exothermic reaction temperature of actual compressor deposits in relation to the calculated temperature of adiabatic single stage compression with increased pressure and intake air temperature. These curves not only indicate the desirability for limiting discharge temperatures to a safe value but suggest the use of automatic, temperature actuated shutoff mechanisms to avert possible accidents from operation at abnormally high temperatures. These mechanisms would also be of value in protecting against possible piston seizure and scoured cylinders which might be encountered from excessive discharge temperatures or valve failure.

CONDENSATION AND COMPRESSOR COOLING

Water can affect compressor lubrication in several ways. If it condenses on the cylinder walls it will interfere with lubrication and cause wear. If it is present in any portion of the system rusting may occur. Rusting in turn can result in excessive wear of either the rubbing surfaces of the compressor or connected pneumatic machines. With certain gases such as H_2S the presence of water may also cause serious corrosion difficulties. The same five oils previously described were subjected to the ASTM Rusting Test, the Humidity Cabinet Test and their rust protection qualities compared. It will be noted from Table V that the rust and oxidation inhibited oil and the detergent oil offer the best rust protection. If good water separation is desired, the inhibited type oil is preferred. Where water is actually condensing on the cylinder walls, then an emulsifiable lubricant is needed and a compounded oil is preferred although a detergent oil may sometimes be used.

To determine where condensation occurs in a compressed air system, the relative humidity has been calculated at various points. From Table VI it will be noted that beginning with air having a relative humidity of 100%, the only place the air

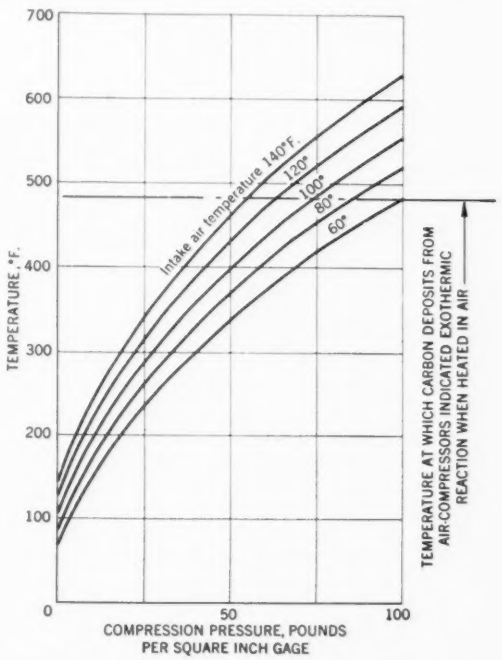
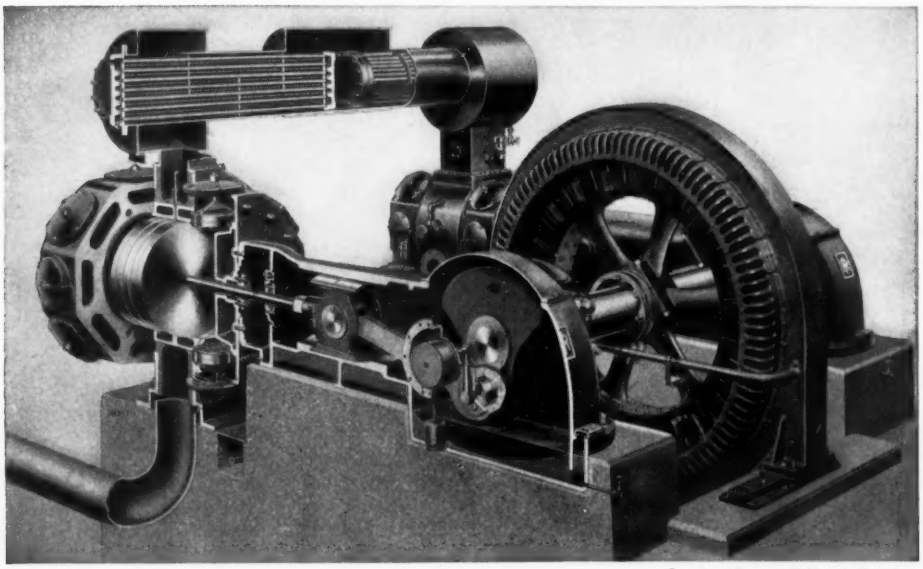


Figure 8 — Relation of temperature of single-stage adiabatic compression to temperature at which carbon deposits from air compressors were found to exhibit exothermic reaction.

From: United States Bureau of Mines Report of Investigations No. RI-4465, by H. W. Busch, L. B. Berger and H. H. Schrenk, June, 1949.



Courtesy Ingersoll-Rand Company

Figure 9 — Duplex, double acting reciprocating compressor. Cylinders are lubricated from mechanical lubricator and bearings from pressure system.

becomes saturated in the entire compressed air system is in the aftercooler and in the distribution lines. Thus an emulsifiable oil is seldom needed, except where the compressor cylinder jacket cooling water is considerably below atmospheric temperature, or inter-cooling is insufficient and supersaturated air reaches the higher stage cylinders. Entrained moisture will adversely affect cylinder lubrication and the intercoolers, separators and knockout drums should be well designed to prevent carryover of liquid particles. In multi-stage machines the cooling water should be circulated first to the intercoolers, then to the low pressure cylinder and last to the high pressure cylinder. To reduce the possibility of condensation, the jacket temperature of the high pressure cylinder should be at least 15° F. higher than the intercooler temperature.

BEARING LUBRICATION

Compressor bearings are usually lubricated by force feed or splash systems although other methods are occasionally employed. As the bearings are usually well designed for the loads encountered and are made of relatively non-corrodable materials very few lubrication problems are encountered. For most compressors a good grade straight mineral oil may be used and if possible the same grade oil as used for cylinder lubrication. However, manufacturers recommendation must be followed in this respect to insure the proper viscosity for the particular machine. Where compressors may be equipped with corrodable type bearings such as those containing lead either in the alloy form, such as a lead base babbitt, or in the pure state, as in the case of dispersed lead in copper lead mixtures, the oil should be suitably fortified to protect against corrosion. While bearing corrosion has not been a problem in compressor lubrication, such a possibility cannot be overlooked with the design of new machines. This is a lubrication responsibility of the bearing and compressor manufacturers together with the oil industry.

SELECTION OF LUBRICANTS

The selection of lubricants to perform the various functions previously outlined will depend on the type of gas compressed, the type of compressor

TABLE V
Water Reaction

Oils	*Anti-Rust Rating ASTM D-665*	*Humidity Cabinet Rating AN-H-31*	*Emulsifying Tendency*
Inhibited Naphthene	1	2	Non-emulsifying
Detergent Paraffin	2	1	Emulsifiable
Compounded Naphthene	3	3	Emulsifiable
Straight Paraffin	4	5	Non-emulsifying
Straight Naphthene	5	4	Non-emulsifying

TABLE VI

Condition of Air Passing Through a 100 Pound Single Stage Air Compressor

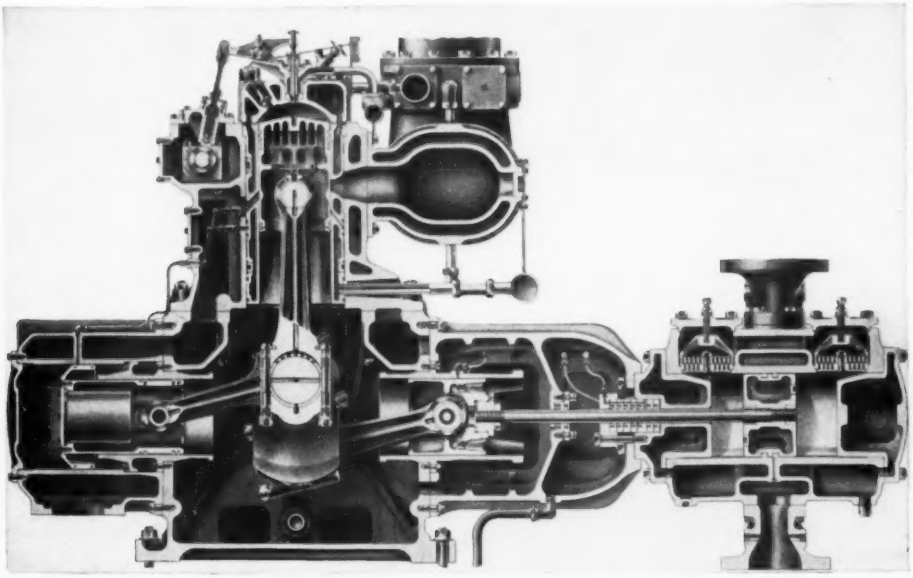
	Gage Pressure p.s.i.	*Temperature °F.*	*Relative Humidity, %*
Atmosphere Intake	0	65	100
Beginning of Compression	0	75	74
15-lb. Compressor	15	172	12
End of Compression	100	485	1
Aftercooler (*a*) 138°F.	100	138	100
Leaving Aftercooler	100	80	100+
End of transmission pipe	97	65	100+
Tool exhaust	0	35	43

and the operating conditions including pressures and temperatures. These factors have been considered in a careful study of the physical and chemical properties of lubricating oils as well as their service performance characteristics. From a practical standpoint the secret of good lubrication is to maintain a film between rubbing surfaces without impairing their action by the formation of harmful deposits. Since these films may be affected by speeds, loads, pressures, temperatures, contaminating materials and reaction with the particular gas being compressed, considerable care should be exercised in selecting compressor lubricants. For these reasons it is difficult if not impossible to draw up specifications which will define the properties desired in a lubricant. In fact rigid specifications may actually rule out the use of superior lubricants for a particular service. Therefore, it is recommended that the purchaser limit such specifications to cover the more important physical characteristics such as viscosity and pour point, and a description of the particular type of service intended. The following discussion outlines some of the more important considerations given in the selection of compressor lubricants.

AIR COMPRESSORS

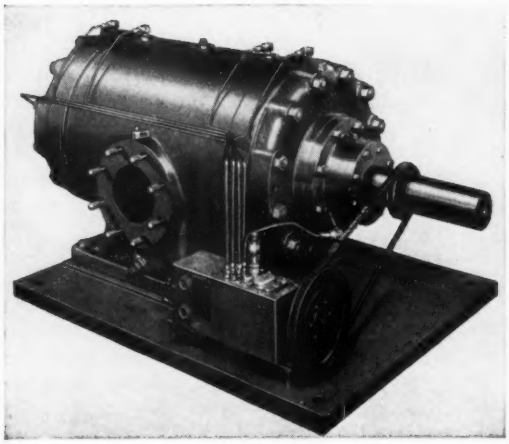
Under normal conditions any good grade power plant or industrial oil will satisfactorily lubricate a large majority of air compressor installations. For special applications, however, the oil must be more carefully selected. Where valve deposits are encountered a straight or inhibited naphthenic oil should be used. The rust and oxidation inhibited naphthenic oils are recommended where protection from rusting of the interior surfaces of the air compressor, intercooler, aftercooler, receiver, or distributing lines is desired. They are especially recommended for units in marine service or where humid conditions are encountered as well as for units in intermittent or standby service. The rust and oxidation inhibited oils are also recommended where crankcase oil temperatures are relatively high. Heavy duty detergent type oils may be used in some units to provide improved cleanliness and protect against wear and oxidation; however, from a discharge valve deposit standpoint, the straight or inhibited naphthenic oils are preferred.

If water is condensing on cylinder walls, a compounded naphthenic oil, which will emulsify with



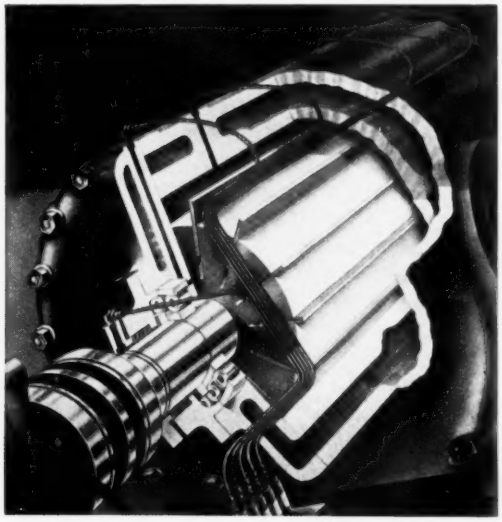
Courtesy Clark Brothers Company

Figure 10 — Cross section of gas engine driven compressor unit.



Courtesy Allis Chalmers

Figure 11 — Sliding vane rotary compressor. Note position of lubricator lines to cylinder and shaft seal.



water is recommended. Compounded oils are not recommended for crankcase lubrication because of their poor stability and water separation characteristics. Where low starting temperatures are encountered the high viscosity index paraffinic oils should be selected. Where oil free air is required, such as for food processing, diving operations, or instrument air, the compressor is either built as a non-lubricated unit or suitable oil traps and separators are provided to remove any entrained oil particles. To reduce the possibility of oil vapors being carried over a straight mineral non-volatile oil of fairly high viscosity may be necessary. The lubrication of high pressure air compressors may vary considerably with design and the heavier paraffinic oils are sometimes recommended to provide a satisfactory piston ring and stuffing box seal. However, where valve deposits occur, the naphthenic oils should be used for cylinder lubrication.

GAS COMPRESSORS

Lubrication of gas compressors requires the consideration of several additional factors which are not encountered with air compressors. These include the thinning of the oil by dissolved gas, the sludging effect of the gas on the oil, the condensation of gas in the compressor cylinder, and the corrosive tendency of the gas. Depending on the viscosity required for the pressures and cylinder temperatures, straight mineral oils are recommended for compressors handling such gases as ammonia, carbon monoxide, helium, hydrogen, neon and nitrogen. Well refined straight mineral oils are recommended for carbon dioxide, sulfur dioxide, hydrogen sulfide, and nitrous oxide. As these gases are corrosive in the presence of moisture, steps should be taken to keep the oil and gas as dry as possible. Compressors handling such gases as oxygen, chlorine, hydrogen chloride, nitrogen dioxide and nitric oxide should be built so that no lubrication is required.

In the compression of hydrocarbon gases the absorption and solvent action of gas in the oil and the washing effect of the condensed gas on the lubricating oil film become important factors. Entrained water will adversely affect lubrication and the presence of unstable gases may cause excessive deposits in cylinders, valves and lines. Entrained dirt, metal chips, pipe scale, rust and other abrasive solids can also result in accelerated wear conditions. Provided the gas is dry and clean, properly refined straight mineral oils are recommended. Due to the absorption of the gas in the oil, the viscosity should be approximately one grade higher than for compressing air. Where the compressors handling natural gas are driven by gas engines it is common practice to lubricate the compressor cylinders with the same grade straight mineral oil as used in the engine crankcase at moderate discharge pressures. The effect of gas absorption on viscosity will depend on the particular gas, pressure, temperature, and the type oil. Table VI illustrates the reduction in viscosity determined for several oils when saturated with natural gas at 3000 psi gage.

These data indicate the need for considerably higher viscosity oils at these pressures; however it will be noted that the extent of viscosity reduction drops off rapidly with increased temperatures. Therefore for increased pressures the higher viscosity steam cylinder oils are recommended.

If the gas has a tendency to condense on the cylinder walls a heavy compounded oil may be used to resist the washing action. Compounded oils may also afford some protection when the gas con-

TABLE VII
Effect of Absorption of Natural Gas on Viscosity

Oil	Viscosity Saybolt Universal Seconds 100°F.	Viscosity Saybolt Universal Seconds 210°F.	Viscosity Index	Ratio of Absolute Viscosity at Atmospheric Pressure to that at 3000 psi gage. 85°F.	120°F.	154°F.	186°F.
Commercial SAE 30 Oil	519	67	104	11.6	5.1	3.5	2.8
Bright Stock plus 200 Second Neutral Blend	440	57	76	10.3	5.3	4.7	—
Bright Stock plus Kerosine Blend	507	67	108	8.7	4.1	2.8	2.4
Bright Stock	2975	165	94	—	8.7	4.1	3.9
Refined Castor Oil	1370	105	94	—	2.4	2.0	1.8

From: J. S. Swearinghan and E. D. Redding, "Industrial and Engineering Chemistry," 34, 1496-1498 (1942).

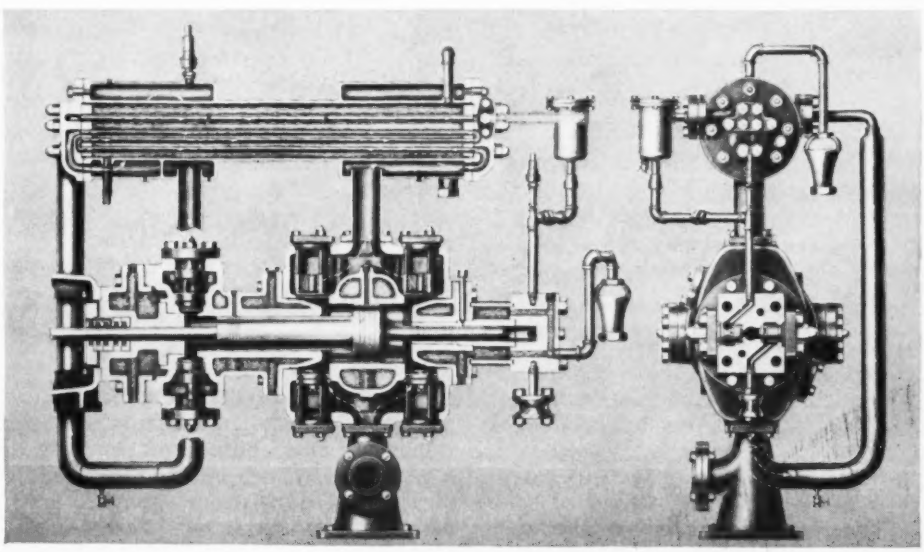
tains water. However, where condensation of either the gas or moisture is encountered it is advisable to eliminate this condition by increasing jacket temperatures well above the dew point and if practical above the critical temperature of the gas. Although increasing the jacket temperatures will decrease compressor efficiency, this may be necessary to obtain satisfactory performance.

Entrained liquid either from the gas or water will seriously affect lubrication and in sufficient amount can result in cylinder failure. In such cases well designed knockout drums, filter blankets, or other suitable devices are desired to prevent the carry-over of entrained particles.

The presence of unstable and corrosive gases may cause sludging and excessive wear and deposits. In such cases a chemical analysis of the gas and sludge or deposits should be made. Depending on the nature of the contaminant it may be desirable to install suitable scrubbers or absorbers to affect complete removal. Other steps may be taken to reduce the deposit forming tendencies by flooding the cylinders with extra oil or by injecting absorber oil into the intake gas stream. This action, however, should not be taken without a thorough knowledge of the contaminating factors and the particular operating conditions.

REFRIGERATOR COMPRESSORS

As with gas compressors, the lubrication of



Courtesy Chicago Pneumatic Tool Company

Figure 12 — Three-stage high pressure compressor unit employing forced feed lubrication to all cylinders and stuffing box.

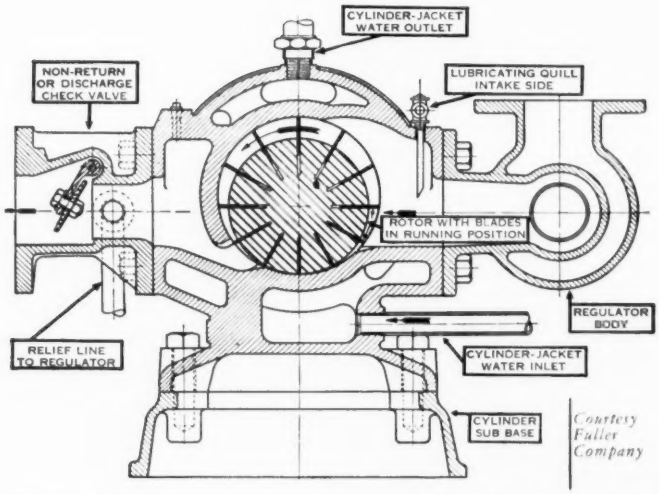


Figure 13 — Sliding vane rotary compressor. Lubricant fed into intake air through lubricating quill.

refrigeration compressors is a specialized field requiring a thorough knowledge of the operating conditions for the particular gas compressed. In most cases, however, the naphthenic oils with low pour points, and good water separating characteristics are recommended.

ROTARY COMPRESSORS

The rotary vane type compressors such as used in many portable type air compressor units require an oil having sufficient viscosity to prevent wear and to seal the rubbing surfaces. The oil must also serve as a heat transfer medium to remove the heat of compression. Good water separating characteristics are also required. Either straight mineral oils or those containing rust and oxidation inhibitors are recommended.

CENTRIFUGAL BLOWERS

The only lubricant required for centrifugal blowers is for the bearings which are usually the anti-friction type and are usually grease lubricated. The particular grease selected should be of the highest quality for the type bearing and service condition.

AXIAL FLOW COMPRESSORS

The bearings are also the principal elements requiring lubrication on the axial flow compressor and a light viscosity rust and oxidation inhibited oil is preferred.

VACUUM PUMPS

Vacuum pumps are similar in operation to a compressor except they operate at an intake pressure below atmospheric and discharge at pressures at or near atmospheric. Relatively viscous low volatile paraffin base oils are usually recommended. These oils have lower evaporation rates and provide an adequate seal to prevent leakage. As the discharge temperatures are somewhat lower than for compressor operation the naphthenic oils are not required. In some vacuum pump installations, it is desirable to install coolers and water separators to prevent excessive amounts of moisture or liquid from impairing cylinder lubrication. Where moisture is entering the unit but is not condensing on the cylinder walls a rust and oxidation inhibited oil, having good water separation characteristics, is preferred. However, where condensation is occurring on the cylinder walls, a compounded oil is desirable to emulsify with the water and provide lubrication. For gases other than air, the heavy duty detergent oils may provide improved protection against the formation of deposits or corrosive wear; however the solvent action of the gas may be such that a properly refined straight mineral oil is preferred.

CONCLUSION

Some of the more important problems associated with compressor lubrication have been presented in this discussion. Although the proper selection and application of lubricants play an important part in achieving long periods of trouble-free service, it is equally important that proper attention be given to the design, installation and operation of compressor units. Because of the many different types of compressors operating under such a wide range of operating conditions with so many different gases, it is necessary that compressor builders, operators, and lubrication engineers work together to obtain the most efficient dependable and economical compressor performance.

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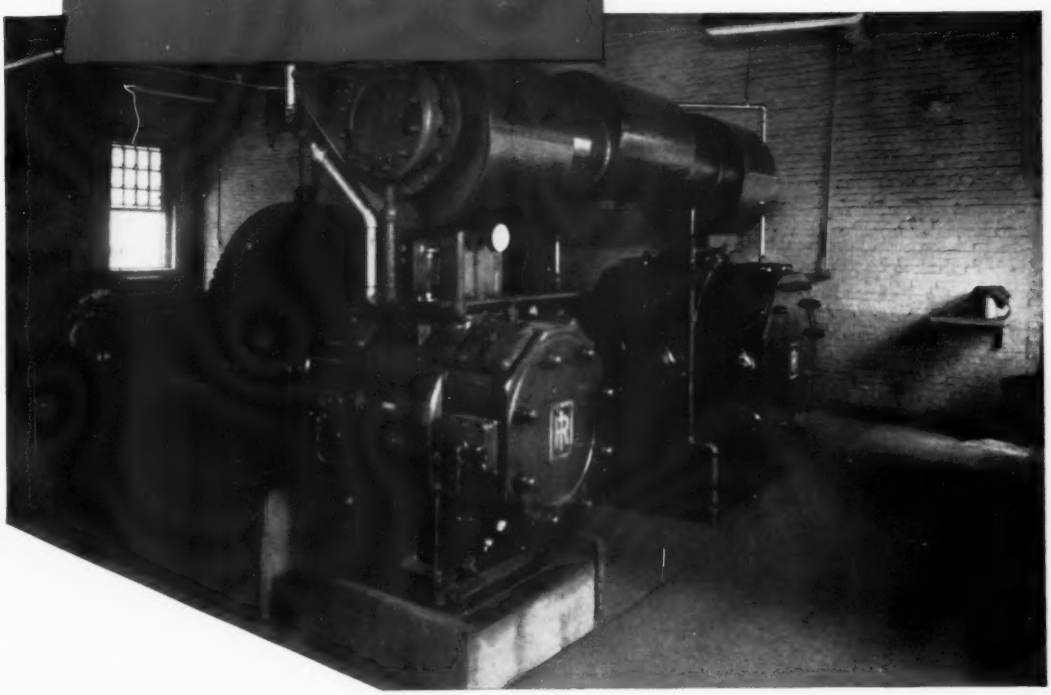
GOLDEN RULE for air compressor lubrication



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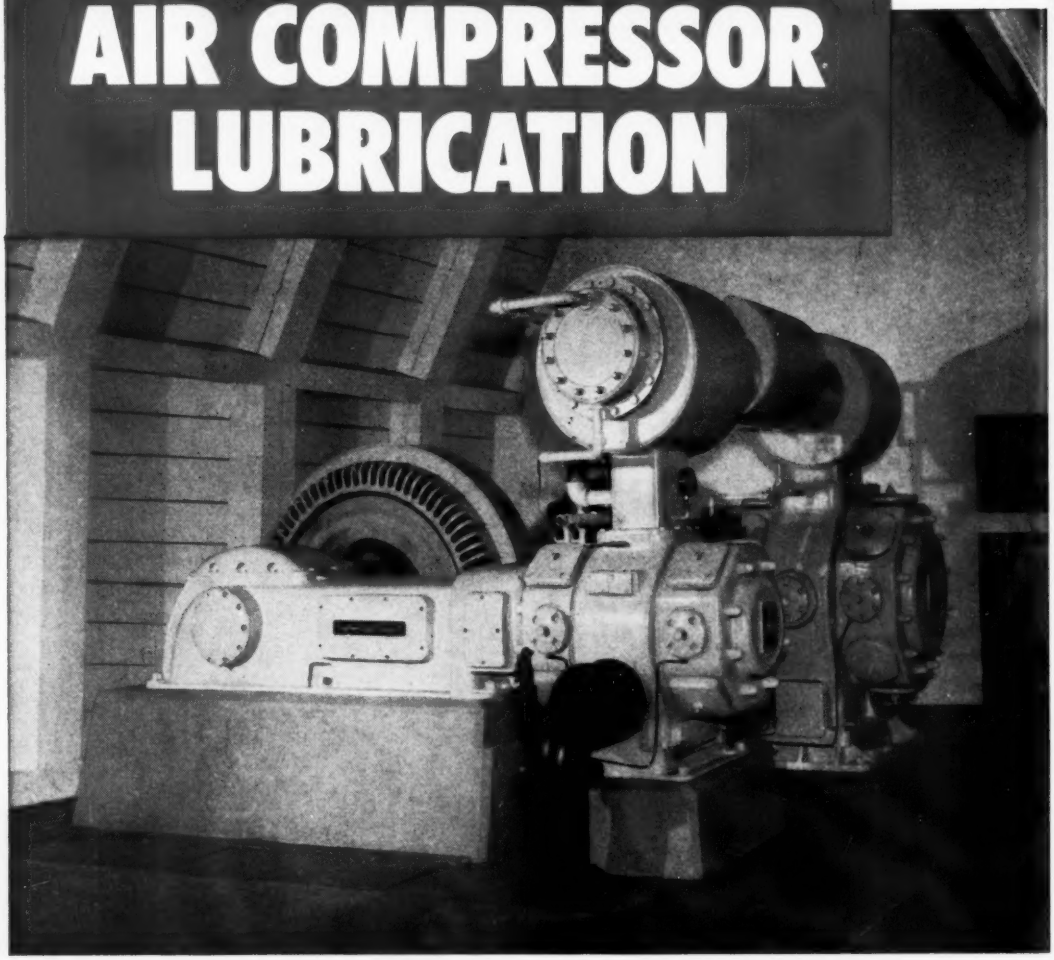
FOR ALL OPERATING CONDITIONS

2 facts to remember about

AIR COMPRESSOR LUBRICATION



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